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STATUS REPORT ON THE WATER QUALITY OF MOOSE LAKE

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OVERVIEW

Lake users and property owners at Moose Lake have been increasingly concerned about the lake's water quality. Algal blooms appear to be very intense, inhibiting recreational activities. After a series of meetings with the local municipalities, Alberta Environment agreed to assess the situation. This assessment included a septic leachate survey during the summer of 1991, an evaluation of data from monthly lake samples collected each summer since 1983 and historical data from 1973 and 1974.

Over the 1983-1990 period, there seemed to be a trend toward increasing amounts of algae in the water (as measured by chlorophyll a concentration). But the highest average chlorophyll a concentration in all the years studied was in 1974, and levels in 1991 were below average. This seems to suggest that the amount of algae in the lake is not increasing over the long-term, although levels vary considerably year to year, depending in part on climatic factors. Based on summer average chlorophyll a concentration, Moose Lake is eutrophic or highly productive.

Abundant populations of algae in lakes result from high concentrations of nutrients. The nutrient of most concern is phosphorus; if average phosphorus levels in the lake increase, it may be expected that algae will become more abundant. Sources of phosphorus for Moose Lake include run-off, precipitation, inflow from other lakes, sewage and the bottom sediments. During late summer, when algal blooms occur, the most important source is the phosphorus-rich bottom sediment.

Septic systems in the Moose Lake watershed may not be a major source of phosphorus to the lake. The septic leachate survey, although preliminary, indicated only background levels of fecal coliform bacteria and phosphorus around most of the shoreline. Additional investigation is warranted, however, because leaking septic systems could pose health risks and localized water quality problems.

Additional investigations also should be conducted on the lake and its watershed to improve both internal and external nutrient loading estimates. These might include a reconnaissance of the watershed, coring of the lake bottom, a sewage facility inventory and additional sampling of the lake in summer. The information that is presently available on Moose Lake provides an excellent starting point for discussions about future management directions, including these sampling programs.

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ACKNOWLEDGEMENTS

Several permanent and seasonal rangers of Moose Lake Provincial Park conducted summer sampling from 1983 to 1991. Technical coordination of the program for the Environmental Quality Monitoring Branch of Alberta Environment was handled in recent years by John Willis. Mike Bilyk and Treva Mailer of the EQMB conducted the septic leachate survey. Meteorological, inflow and water level information for Moose Lake was provided by the Technical Services Division of Alberta Environment.

Samples were analyzed by the EQMB (phosphorus and chlorophyll *a*) and by the Alberta Environmental Centre at Vegreville (other nutrients, major ions). Bacteriological samples were analyzed by the Provincial Laboratory of Public Health.

Dave Trew reviewed a draft of this report.

STATUS REPORT ON THE WATER QUALITY OF MOOSE LAKE

Moose Lake is a popular, scenic recreational lake situated 3.5 km west of the town of Bonnyville in east-central Alberta. The lake's general characteristics, including water quality, are described in the "Atlas of Alberta Lakes" (Mitchell and Prepas 1990) and additional information is available in the Alberta Environment brochure "Moose Lake" published in 1989.

Over the past few years, lake users have been concerned that water quality in Moose Lake is deteriorating. The lake appears very green and murky, and the Town of Bonnyville's water supply, which is drawn from Moose Lake, has been difficult to treat. This condition is caused by dense populations of algae, which are a direct result of an abundant supply of nutrients such as phosphorus and nitrogen. Potential sources of nutrients include run-off from the watershed during snowmelt and rain, precipitation and dust, the bottom sediments, groundwater and sewage effluent. Lake users believe that sewage effluent from shoreline development is the primary cause of water quality problems in Moose Lake. The M.D. of Bonnyville, the Town of Bonnyville and the summer villages of Pelican Narrows and Bonnyville Beach requested that Alberta Environment determine the cause and cure for the lake's apparent declining water quality.

After a series of meetings between Alberta Environment and the municipalities, it was decided that Alberta Environment would conduct a septic leachate survey of Moose Lake during the summer of 1991. This was to be a "first cut" to determine whether leaking septic systems were a

problem. In addition, staff of Moose Lake Provincial Park and Alberta Environment conducted the annual sampling program on the lake in 1991. This status report is an update on present knowledge of water quality in Moose Lake, and includes results of the septic leachate survey, an overview of trends in fertility based on the monitoring program conducted by Park staff between 1983 and 1991, and an estimate of the quantity or load of phosphorus contributed by the bottom sediments and other major sources each summer.

The purpose of this report is to summarize all present knowledge on the lake's water quality so that possible directions for lake management may be determined.

Background Studies

The first water quality study on Moose Lake was conducted in 1966 by a fisheries biologist. He stated that Moose Lake was one of the most productive eutrophic lakes in central Alberta, and noted oxygen depletion in the bottom water in summer (McDonald 1967). Another study was conducted in 1973 and 1974 by researchers at the University of Alberta. This study was designed to obtain background information in response to concerns that water quality in the lake was deteriorating; chlorophyll a, Secchi depth, dissolved oxygen and major ion data were obtained. The study confirmed that the lake was eutrophic, or nutrient-rich, and subject to blue-green algal blooms (Gallup 1977). In 1980 and 1981, Alberta Environment studied water quality in Vezeau Bay to determine the impact of a proposed stormwater diversion to the lake from the town of Bonnyville. Although data are available, a report was not

produced. The stormwater diversion was licensed, but the expected development in the area has not occurred. In 1983, Alberta Environment established a lake sampling program with Alberta Recreation and Parks on Moose and other recreational lakes associated with Provincial Parks. This program is on-going, and samples have been collected every year since 1983. Thus, the data base on Moose Lake is quite extensive, although there has never been a field study to confirm sources and quantities of nutrients entering Moose Lake.

Methods

Most lake studies conducted by Alberta Environment are designed to provide information on the lake as a whole, so that trends in nutrient status may be detected. Moose Lake was sampled by collecting individual samples from 10-15 offshore locations and combining these into a single sample container, so that a representative whole-lake composite sample was obtained. Each sample was collected to the depth of light penetration, as measured by a Secchi disk or underwater photometer. The composite sample was analyzed for chlorophyll a, a measure of the quantity of algae in the water, and total phosphorus, perhaps the most important nutrient governing recreational water quality in lakes. Major ions were analyzed quarterly as well. Twice per year, dissolved oxygen, specific conductance, pH and temperature were measured directly in the lake.

All of the studies conducted by Alberta Environment since 1980 were done in this way, including the sampling by Park staff. Samples collected by D.N. Gallup in 1973 and 1974 were obtained as separate grabs

from one central location on the lake, and therefore these earlier data may not be perfectly comparable with those of other studies. In addition, the data from samples collected in Vezeau Bay in 1980 and 1981 are not directly comparable to those from whole-lake samples.

In July 1991, developed shoreline areas were surveyed with a septic leachate detector, an instrument that has been evaluated by Alberta Environment on other Alberta lakes (Mitchell 1982). The detector is calibrated with local sewage and lake water. Using a boat, the operator moves a probe along the bottom and water is pumped through the instrument. It responds to increases in specific conductance and fluorescence, both of which are higher in sewage than lake water. When the instrument indicates increases in both of these, bacteriological and nutrient samples are collected. Only the bacteriological data are used to indicate the presence of possible sewage contamination, although the nutrient data provide corroborative evidence.

A mass balance approach was used to estimate the quantity of total phosphorus (P) contributed by the bottom sediments each summer (internal P loading), as opposed to P contributed from external sources. The difference between the lowest phosphorus concentration, which usually occurs in June, and the highest concentration, which usually occurs in late August, represents an increase in the total quantity of P in the lake. If phosphorus entering the lake in streams, precipitation, etc., during this period is subtracted, the remainder must have come from the bottom sediments (including groundwater entering the lake through the bottom).

Inflows via precipitation directly onto the lake surface and via

streams were provided by Hydrology Branch (1991). Flow-weighted P concentrations calculated for streams entering Baptiste and Wabamun lakes were applied to Moose Lake run-off inflows to yield a total quantity of P input for the time period. Similarly, a phosphorus coefficient for precipitation from the Lake Wabamun study (Mitchell 1985) was applied to the proportion of rainfall actually measured for Moose Lake for the time period. Sewage inputs were considered negligible; any actual P contribution from sewage would be included in the internal load estimate.

Outflow losses were also considered. Flow in the outflow stream, the Mooselake River, was negligible during these years, but the town of Bonnyville withdrew water for its municipal supply. It was assumed that the P concentration in the lake during the period was the same as in the withdrawal water, and mass in this outflow was calculated and added to the estimate for the total P mass in the lake:

internal load = change in mass in lake + outflow mass - external input

Long-Term Fluctuations in Trophic Variables

Data on chlorophyll a concentration [CHL], an estimate of the quantity or biomass of algae suspended in the water, and major ions, the electrically-charged forms of certain chemicals, are available for Moose Lake since 1973, but phosphorus measurements from the 1970s and from 1985 are unreliable. Chlorophyll a is an excellent indicator of recreational water quality because it is a measure of a lake's green-ness. Figure 1 shows average summer [CHL] for all of the years sampled. Samples collected in 1980 and 1981 are from Vezeau Bay only, and are not

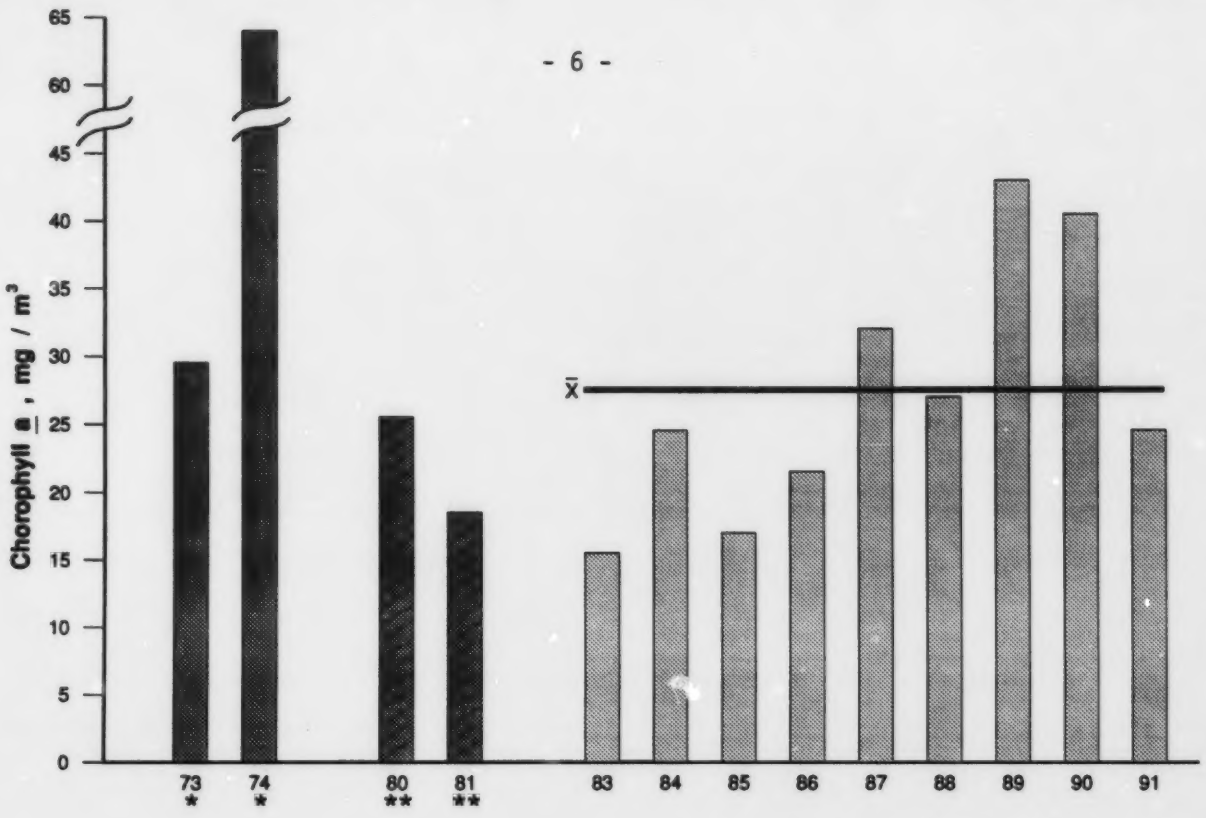

Figure 1. Average chlorophyll a concentrations in Moose Lake 1973-1991.

Average for July 1 - Sept. 15 period; each year average is based on 3-4 euphotic composite samples. Horizontal line is overall average 1983-1991.

*euphotic x̄ at one central site **Vezeau Bay only

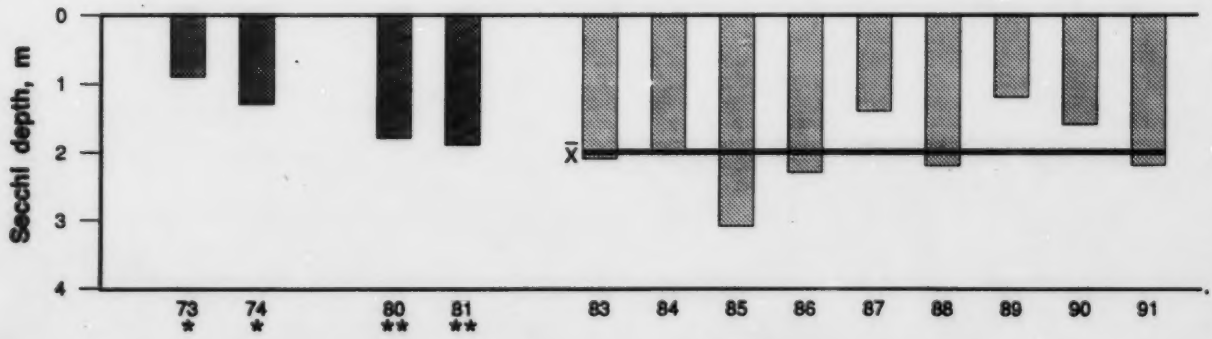

Figure 2. Average Secchi depths in Moose Lake 1973-1991.

Average for July 1 - Sept. 15 period. Each year average is based on 3-4 measurements. Horizontal line is overall average 1983-1991.

comparable to those of other years because Vezeau Bay is deeper than the rest of the lake. Figure 2 presents average Secchi transparency for the same sampling dates. As might be expected, transparency declines when algal populations increase, so that a high average [CHL], as in 1989, results in a low average Secchi depth.

The average chlorophyll a concentration for July-September each year increased between 1983 and 1990. Although the [CHL] data for 1987-1990 are significantly higher than those for 1983-1986, the 1991 data are below the overall average, and the 1973-74 data are above average. Thus, if only the 1983-90 data are considered, a trend toward declining water quality seems apparent, but if all years are considered, water quality in Moose Lake is not deteriorating. Average Secchi depths over these years support this conclusion, as do Secchi measurements from July 1966 (1.7 m - 3.5 m; McDonald 1967), which fall into the range observed in later years.

It seems likely that algal biomass in lakes undergoes high and low cycles, depending largely on climatic factors such as amount of spring run-off, wind and air temperatures over summer. The detection of genuine trends will require additional years of sampling.

Although many lake users believe that water level plays a major role in governing water quality, water level per se is probably less important than nutrient inputs at critical times via snowmelt, rainstorms or internal loading. Thus, the very high [CHL] in 1974 may have resulted from high nutrient loads from above-normal run-off that spring. On the other hand, very low water levels might result in greater warming of the sediments and enhanced phosphorus recycling (internal loading). This is

contrary to the situation in 1991, however, when the average [CHL] was below the long-term average and the water level was extremely low. There appears to be no trend in P concentrations over the 1983-91 period, although data points are fewer than for [CHL]. If P levels are not increasing in the lake, it is likely that recreational water quality is not declining. The high [CHL] the past few years may simply result from optimum growing conditions. Note that these comments pertain to offshore conditions, rather than along the shoreline. Aquatic vegetation has not been monitored in these studies.

Phosphorus Supply from the Bottom Sediments

It has been estimated previously that on average, approximately 10,000 kg of P enters Moose Lake in a year (Table 1). This estimate is based largely on coefficients for phosphorus in run-off and precipitation derived from other Alberta lakes, because actual P inputs to Moose Lake have not been quantified. However, other studies have shown that this "desk budget" calculation is a reasonable approximation for scoping out a lake management issue. This supply of P is derived from sources outside of the lake. An additional source is the bottom sediments, which have been accumulating P since the lake's origin about 10,000 years ago. As the sediments warm over the summer, short-term changes in oxygen levels occur within and immediately above the sediments. Under these conditions, P adsorbed to the sediment particles moves into the water, stimulating algal growth. For many shallow, productive lakes, this is a major source of phosphorus, and the result is dense blooms of algae during late summer when external inputs of P are minimal. Often, such

Table 1. Theoretical annual phosphorus supply to Moose Lake, kg/year.

EXTERNAL[1]		PERCENTAGE OF TOTAL SUPPLY
Surface run-off		
Forested/bush	1998	13
Cleared/agricultural	5683	38
Urban/cottage	1247	8
Precipitation, dust-fall	898	6
Flow from other lakes in watershed	370	2
Sewage effluent	78[2] (2000)[3]	<1 (12)
TOTAL EXTERNAL	10,274	
INTERNAL[4]	4810	32
TOTAL	15,084	100

Notes:

1. Source "Moose Lake", brochure produced by Environmental Quality Monitoring Branch, Alberta Environment, July 1989.
2. Estimated portion to enter lake based on other studies in Alberta.
3. Total supply if all sewage generated by shoreline development enters lake.
4. Estimated from phosphorus concentrations in lake 1983-1989 (Table 2).

lakes are considerably more productive than their external nutrient supply would suggest.

There is at present no reliable technique to measure P internal loading directly, but a mass balance over the summer period provides an estimated quantity of P from this source. Table 2 presents a summary of internal and external P loads for the summer periods 1983-89 between dates of the lowest and highest measured lake P concentration. The external load does not include an estimate for sewage inputs. The external supply presented in this table is considerably smaller than the long-term annual supply (10,000 kg) because inflows and P concentrations are lower in mid-summer than during spring and early summer. In addition, run-off inflow during the 1983-89 summer period was only about 40% of normal (Hydrology Branch 1991).

Because the bottom sediments provide a large supply of phosphorus during the summer, one might expect to see higher [CHL] with larger internal loads. There is a fairly good relationship* between the maximum chlorophyll a concentration and the calculated internal load for these years, although the relationship between average [CHL] and internal load is poor. It is obvious that internal loading is very important in Moose Lake, and it appears to have a major influence on how green the lake will get each summer; in fact, internal loading probably masks effects from other sources.

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* Linear regression, $r^2 = 0.89$, n=6

Table 2. Internal and external phosphorus supply to Moose Lake 1983-89.

YEAR	TP CONCENTRATION, mg/m^3 START (date)	END (date)	NUMBER OF DAYS	EXTERNAL[1] SUPPLY, kg	INTERNAL[2] SUPPLY, kg	TOTAL	$mg/m^2/day$ INTERNAL LOADING RATE	Chl $\underline{a}$[3] CONC. mg/m^3
1983	30 (June 14)	43 (Aug. 22)	69	1241	1323	2564	0.9	16.1
1984	33 (July 13)	71 (Sept. 3)	52	338	6867	7205	3.2	24.5
1986	24 (June 4)	59 (Sept. 4)	92	978	5819	6797	1.6	21.8
1987	39 (May 23)	66 (Aug. 25)	94	573	4399	4972	1.1	34.0
1988	32 (May 24)	47 (Aug. 17)	85	493	2368	2861	0.7	27.2
1989	26 (May 30)	75 (Aug. 22)	84	444	8087	8531	2.5	43.4
			Average	678	4810	5488	1.7	

1 Calculated by applying flow-weighted concentrations measured at Wabamun and Baptiste lakes to estimated Moose Lake inflow volumes for period, and coefficients from Lake Wabamun for precipitation directly onto the lake. Assumes P input from sewage sources is negligible.

2 Calculated by mass balance: internal P supply = change in P mass in lake + outflow mass - external input mass. Outflow in the Moose Lake River was negligible during these time periods.

3 July 1 to September 15 averages.

Septic Leachate Survey

The sites sampled during the septic leachate survey on July 15-16 are shown in Figure 3. Results for the 12 samples collected are presented in Table 3. All of the results indicate background conditions (i.e., no sewage input) except for site 9 at the southern tip of Vezeau Bay and possibly site 3, which has elevated nutrient levels. The results for these sites are not particularly high; for example, in a similar survey conducted on another lake a week or so earlier, results of greater than 600 fecal coliform counts were recorded in several areas. Both of the Moose Lake sites are near the mouths of creeks draining agricultural areas, so agricultural run-off may be the cause of elevated nutrient and coliform levels. Further investigation of these areas is warranted.

Conclusions and Recommendations

The water quality of shallow, productive Moose Lake varies considerably from year to year. Although there appeared to be a trend toward increasing algae populations (chlorophyll *a*), data from 1991 and the mid-1970s suggest otherwise. The highest summer average concentration of chlorophyll *a* occurred in 1974 after an abnormally high spring run-off. There are undoubtedly many factors that contribute to these annual variations, but climatic conditions probably are the most important. An early, warm spring allows warming of bottom water in unstratified parts of the lake to begin earlier, potentially extending the season that internal loading of P occurs. An additional factor that undoubtedly contributes to variability in average values is the wide

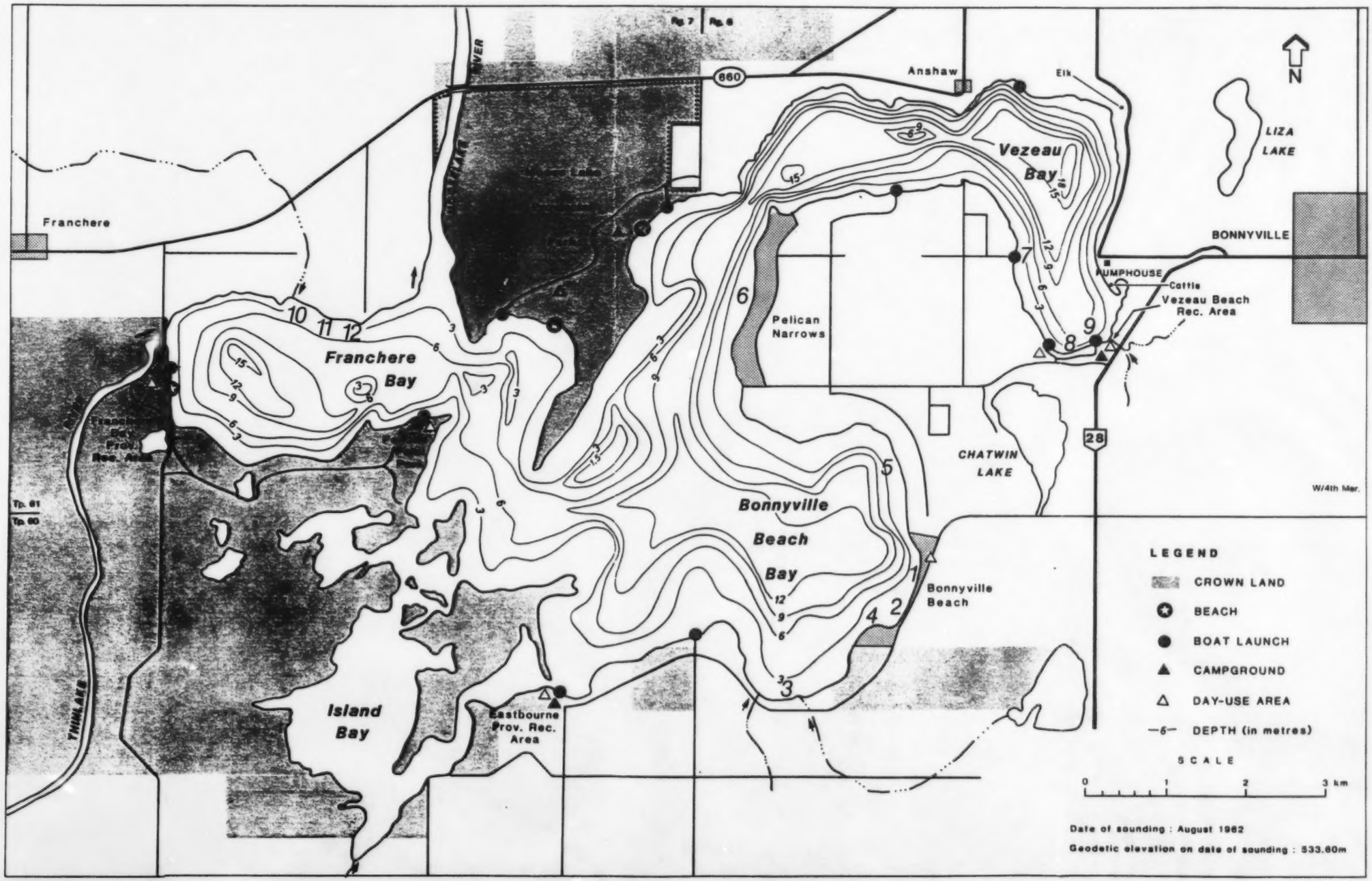

Figure 3. Bathymetric map of Moose Lake. Septic leachate survey sample collection sites 1-12, July 1991.

Table 3. Sampling results - Moose Lake septic survey, July 15-16, 1991 in mg/L or coliform counts/100 mL.

SAMPLE NUMBER	TOTAL COLIFORMS/	FECAL COLIFORMS/	TOTAL PHOSPHORUS	TOTAL NITROGEN	AMMONIA	CONDUCTANCE µS/cm	SODIUM	TOTAL DISSOLVED SOLIDS
1	10	< 10	0.043	1.36	0.017	736	74	439
2	< 10	< 10	0.028	1.29	0.014	736	75	430
3	> 40*	4	0.167	1.95	0.026	738	77	446
4	> 10*	10	0.039	1.36	0.018	745	76	446
5	-*	< 10	0.075	1.90	0.022	738	75	445
6	< 10	< 10	0.055	1.51	0.020	734	75	444
7	10	10	0.028	1.15	0.010	737	75	441
8	-*	10	0.083	1.74	0.015	738	76	442
9	>210	210	0.031	1.18	0.009	734	75	440
10	10	< 10	0.033	1.18	0.010	736	76	442
11	10	< 10	0.049	1.13	0.011	734	77	441
12	< 10	< 10	0.068	1.22	0.012	734	75	446
Moose Lake Average 1990	-	-	0.054	-	-	705	74	432

* Due to the nature of the bacterial growth, an accurate count could not be determined.

interval between sample collection dates each summer.

Internal loading, or recycling of phosphorus from the bottom sediments, appears to be a major factor governing the green-ness of the lake. It was the largest source of phosphorus in the summer during 1983-89, and may represent a third of the total annual supply to the lake. Sewage effluent appears to be a relatively small proportion of this total. Even if every cottage, camp, park and institution put treated sewage effluent directly into the lake, the total P supply from sewage would represent only about 16% of the external supply, or 12% of the total supply. However, the preliminary septic leachate survey conducted in 1991 suggests that sewage is not a major problem in Moose Lake, so that the actual supply of phosphorus from this source is considerably less, perhaps less than 1% of the external supply, as Table 1 suggests. It is very unlikely that sewage is the cause of the blue-green algal blooms that occur in the lake each summer.

On the other hand, leaking or malfunctioning septic systems should not be ignored. The phosphorus in sewage effluent is largely in a chemical form that is bioavailable (readily taken up and used by growing algae and shoreline aquatic vegetation). The phosphorus in surface run-off and precipitation can be considerably less bioavailable. For example, 10 kg of total P derived from surface run-off might have half of the growth potential of 10 kg of total P derived from sewage, because the phosphorus is in a different chemical form. In addition, a leaking septic system could create local problems such as increased plant growth, odors and human health risks in the lake area near the leak. For this reason, property owners with leaking systems should take steps to correct

the problem, or they could be charged under Public Health Act regulations or in some cases under Environmental legislation.

During rain and spring snowmelt, run-off over agricultural land or cottage property contributes a large portion of the supply of total phosphorus; according to Table 1, these sources represent 46% of the total supply. Even though some of this P is in a chemical form that plants cannot use directly, the total amount from these sources is large, so that the bioavailable portion would also be large. Wherever possible, loading of P should be reduced. There are undoubtedly specific areas within the watershed that contribute high concentrations of P, and those along inflow creeks or the lakeshore are particularly important. These might include livestock pasture, fertilized lawns or crops, construction sites, landfills, sewage lagoons, malfunctioning septic systems or any area of concentrated human activity. Any of these areas potentially could be cleaned up so that nutrient export is reduced. Some of these sites could be cleaned up at relatively low cost by the property owner, whereas other sites might require diversion and lagooning of run-off or other mitigative techniques.

It is apparent that there is insufficient information on Moose Lake to determine what could be done to improve or preserve water quality, or even whether anything should be done. The first steps in obtaining this information would be a detailed reconnaissance of the watershed, with a focus on the shoreline and tributary streams, and a determination of historical impacts by coring the bottom sediments. Sampling of streams to confirm external loading estimates and additional septic surveys in summer may be required. A survey of the types of sewage

facilities around the shoreline would also be very useful. The lake should be sampled intensively to obtain additional information on internal loading, as well as more frequently each summer to better assess trends. The management and effort for these studies should be made by the lake users, with assistance from Alberta Environment and the Health Unit. The time needed for such diagnostic studies is perhaps two to three years, after which the focus would be on feasibility of management or mitigation options.

Lake users should understand, however, that such effort may not lead to a visible improvement in water quality. Internal phosphorus loading in Moose Lake will likely compensate for any external nutrient supply reduction, perhaps for many years. If the external load could be substantially reduced, however, the internal loading would gradually diminish, resulting in reduced algal populations and better recreational water quality.

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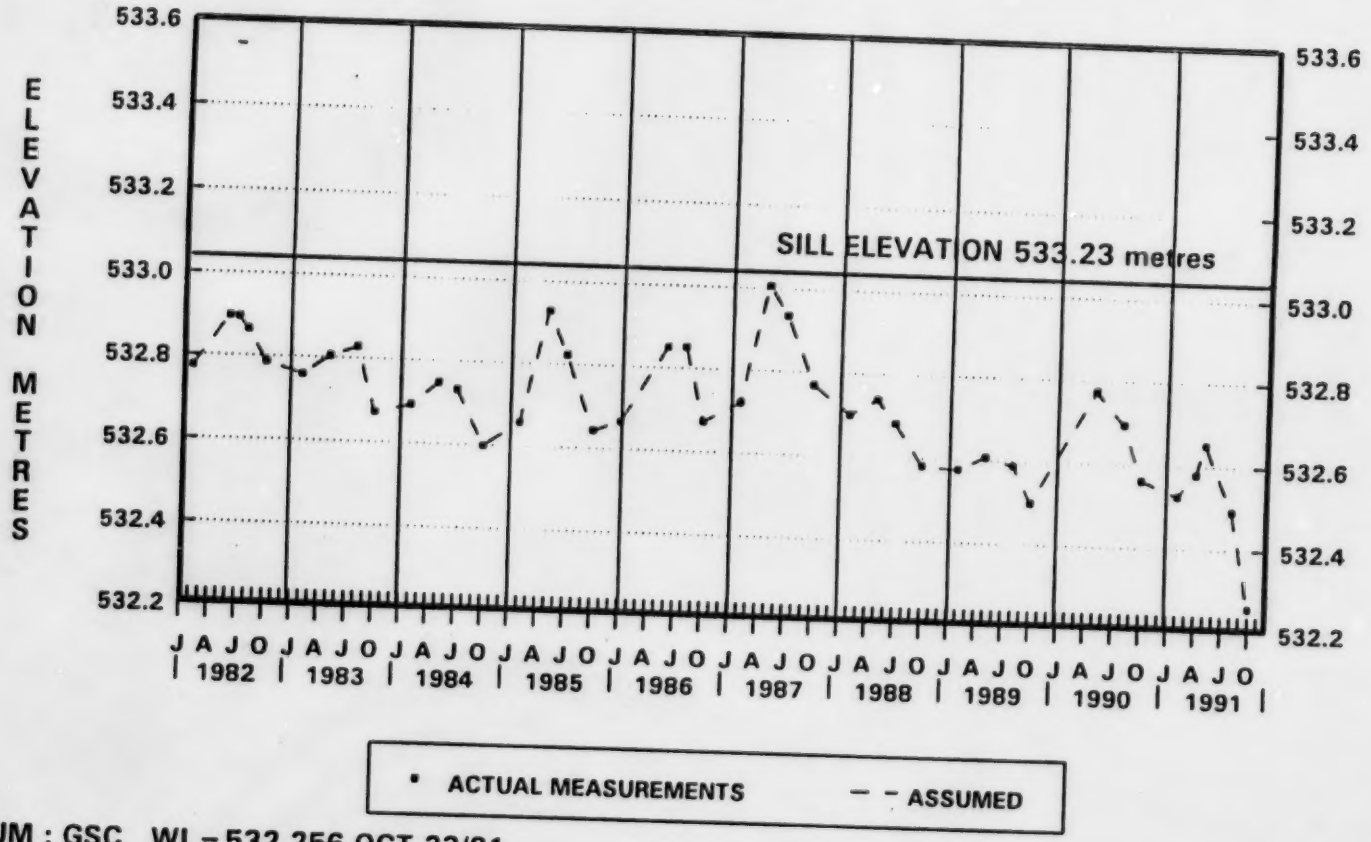
Appendix I. Moose Lake trophic data - July 1 to September 15 averages. Euphotic composite samples.

YEAR	chl *a* µg/L	TP µg/L	SECCHI, m	TDS mg/L	n
1973	29.5	-	0.9	378	2
1974	63.2	-	1.3	345	3
1980	26.0	50	1.7	338	6
1981	18.0	38	1.9	346	5
1983	16.1	39	2.1	369	2
1984	24.5	49	2.0	381	3
1985	17.2	-	3.2	391	3
1986	21.8	46	2.3	404	3
1987	34.0	58	1.4	403	2
1988	27.2	47	2.2	426	2
1989	43.4	60	1.2	435	2
1990	40.2	52	1.6	427	3
1991	24.1	52	2.2	-	2
$\bar{x}$ 1983-91	27.6	50	2.0		
	n=9	n=8	n=9		
	SE=3.22	SE=2.38	SE=0.20		

n = number of samples
SE = standard error

MOOSE LAKE NEAR BONNYVILLE
STATION NO. 06AC911



DATUM : GSC WL = 532.256 OCT 23/91
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